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Creation of the tribological model of contact wear of a rail depending on grinding process parameters

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Background. *The current operating conditions of railway transport characterized by an increase in the power of locomotives, train speeds and carrying capacity, which leads to increased force influences on the railway track. Extreme operating conditions lead to increased wear and damage to rails on the reliability of which depends not only on traffic safety, but also the economic performance of the railway. Defective layers of the material removes from the surface of the rail by the rail grinding process. Thus, provides the required sizes and shape accuracy, as well as surface quality of rails during their operation.*

Objective. *The aim of this work is to develop a tribological model of contact wear of rails during their operation depending on parameters of the grinding process (temperature t, grinding depth of cut* a_e*, grinding wheel speed V).*

Methods. *The research on wear and contact damage of samples of surfaces cut from grinding rails conducted on a friction machine M-22M. The studies were carried out by dry friction of a sample (cut from a rail) with a counter-sample from the material used in the manufacture of railway wheels, for 1 hour, the friction path was 3.60 km. Samples were weighed on a VLR-200 balance before and after the study was performed on the friction machine. As a result, the mass wear value was determined for each sample. A numerical model created in the Ansys program for numerical simulation by the finite element method of the rail-wheel contact to determine the contact pressure distribution and the wear intensity of the rail.*

Results. *Based on the results of tribological studies in the paper established the empirical dependence of the wear intensity of the rail sample on the grinding process parameters. The contact conditions of the rail sample with the counter-sample during the tribological experiment and in real contact of the rail-wheel are different. Therefore, we performed the alignment of that empirical dependence to the actual conditions of contact of the wheel with the rail. The rail-wheel contact simulation performed in ANSYS Workbench. The dependence that given in the paper used in the program. It used to calculate the wear intensity of the rail according to the distribution of contact pressure in the contact zone of the wheel and rail.*

The results of the work can find practical application in railway transport to predict the effect of grinding proces parameters on the wear intensity of the rail.

Conclusions. *The dependence obtained for the approximate value of the rail wear intensity depending on the grinding process parameters (temperature t, machining allowance ae, linear speed of the grinding wheel V) based on the experimental data obtained from tribological experiments on the M-22M friction machine with grinded rail samples. The mathematical model has developed for calculating the contact pressure and the value of the rail wear intensity depending on the number of load cycles in the ANSYS program.*

Keywords*: rail grinding; wear intensity; surface hardening; tribological properties.*

Introduction

The current operating conditions of railway transport characterized by an increase in the power of locomotives, train speeds and carrying capacity, which leads to increased force influences on the railway. Extreme operating conditions lead to increased wear and damage to rails on the reliability of which depends not only on traffic safety, but also the economic performance of the railway [1].

The wear rate of train wheels and rail are affected next parameters: the current load (contact pressure of the wheel on the rail), temperature (in contact), type and speed of the locomotive, environmental effects, physical-chemical modification of surfaces during friction and wear, properties lubricants and lubrication methods. Rails experience alternating bending stresses reaching 240 MPa, and high specific pressures – 2500 MPa during the contact train wheels with rails. In the curved sections of the path with a radius of 350 m or more, wheel slippage is 2 – 3% [2, 3].

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One of the defects that occurs on the rail surface is wave-like wear [4]. The occurrence of such a defect causes the appearance of tracks, a decrease in train speeds, a detrimental effect on rolling stock, an acceleration of failure, an increase in dynamic loads on rails and, as a result, an acceleration of the development of contact-fatigue defects. The occurrence of such a defect causes damage to the track, a decrease in train speeds, a harmful effect on the train, accelerating its failure, increasing the dynamic load on the rails, and, as a result accelerating the growth of contact-fatigue defects.

To prevent the development of wave-like wear first it is necessary to increase the quality of rail production at rail rolling factories, as well as the quality of repairs and current track maintenance, ensuring its uniform elasticity throughout the entire period between repairs.

Efficiency and quality of repair of a rail cloth achieved by timely carrying out profile (all around the perimeter) or surface rails grinding by special grinders, rails grinding trains and allows increasing the inter-repair terms of the way. The process of grinding the contact surface of rails carried out at the expense to the power contact of the kinematic chain "abrasive wheel – machined surface". The design of the grinding machine provides constant perpendicularity to the axis of rotation of the circle relative to the longitudinal axis of the rail. Cutting conditions of each separately working wheel vary significantly depending on the angle of inclination of the grinding head. The work of an abrasive tool closely related to the changes that make the physical–mechanical properties of rails, resulting in a sharp change in hardness in individual sections of the railhead and contributes to toughening the working conditions of grinding wheels.

The urgent problem is to increase the productivity and manufacturability of the processes of grinding rails, to ensure the specified quality and the necessary physical and mechanical properties of their rolling surface. An important task is to create the tribological model that linked the parameters of the grinding process and the predicted value of rails wear, which would firstly optimize the frequency of repair of rails, and secondly, optimize the parameters of the grinding process to decrease the wear of the rail contact surface.

The aim of this work is to develop a tribological model of contact wear of rails during their operation depending on parameters of the grinding process (temperature *t*, grinding depth of cut a_e, grinding wheel speed *V*).

The main tasks set forth in the presented work are:

– Establishment of mathematical dependencies of the influence of grinding process parameters on the wear intensity of rails;

– Creation tribological model that links the predicted value of the wear intensity of rails in real conditions of their operation and parameters of grinding processes.

Results

In previous works [5, 6], experimental studies were carried out to establish the effect of grinding process parameters on the wear intensity of rail grinding samples, their hardness and roughness. Tribological studies performed with samples that cut from the rail contact surface that subjected to grinding [7]. The studies carried out on an M-22 friction machine under the following conditions of contact of the sample with the counter-sample: dry friction, rotation frequency n = 490 min^{-1}, contact force – $P = 100\,N$, friction path – 3.60 km (the experiment performed for 1 *h*). Graphical dependences of the effect of grinding parameters on the values of wear intensities of rail samples obtained and given in [7], based on the data from the experiments.

The following empirical dependencies obtained by approximating the graphical dependencies obtained by the experimental data [7]. The dependence of the hardness on the wear intensity of the rail sample at different values of the grinding depth of cut a_e [7]:

$$
\begin{aligned}
I'(HV, a_e) = a_e^2\left(\left(0.884 \cdot HV - 642.36\right)^2 - 15310.37\right) - a_e\left(\left(0.1257 \cdot HV - 94.35\right)^2 - 459.82\right) + \\
+\left(0.0107 \cdot HV - 7.53\right)^2 - 0.61,
\end{aligned}
\tag{1}
$$

where *HV* is value of the sample Vickers hardness.

We take into account the influence of other parameters (temperature *t* and grinding wheel speed *v*) of the rail grinding process on their wear resistance in the form of influence coefficients. In our calculations, we accepted that the hardness of the rail is 600 *HV*, which will correspond to the minimum wear intensity of rail samples according to the work [7]. Then, the dependence of grinding process parameters of the rail samples on the wear intensity has the form:

$$I(a_e, V, t) = I'(HV, a_e) \cdot k_V \cdot k_t\,, \tag{2}$$

where k_V is coefficient of speed influence on the predicted value of the wear intensity of rail samples, k_t is coefficient of temperature influence on the predicted value of the wear intensity of a rail samples.

The coefficient of speed influence depending on the grinding depth of cut a_e:

$$k_V = (12.52 \cdot a_e - 0.0712) \cdot V - 338.9 \cdot a_e + 2.8453\,. \tag{3}$$

The coefficient of temperature influence depending on the grinding depth of cut a_e:

$$k_t = (-0.925 \cdot a_e - 0.00085) \cdot t - 6.1071 \cdot a_e + 0.9749 . \quad (4)$$

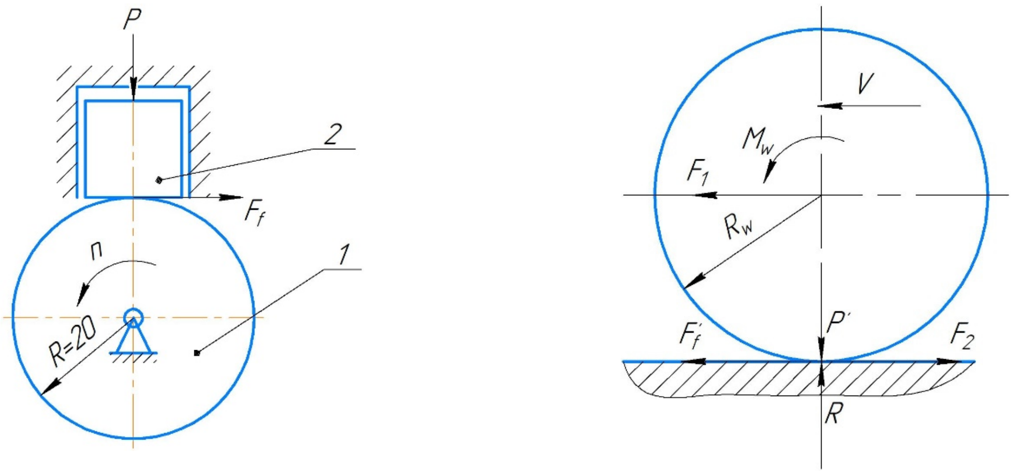
The indicated dependence (2) is valid for predicting the wear of rail samples when performing an experiment on a friction machine. Since the contact conditions of a rail sample with a counter-sample during a tribological experiment and in a real contact of a rail-wheel are different, the empirical dependence (2) is indicated cannot be used to assess the rail wear in the real contact conditions. The dependence (2) can used to perform relative assessments of the influence of grinding process parameters on the wear of rail samples.

During the experiment, sliding friction occurs between the rail sample and the counter-sample (fig. 1. *a*). In a real contact of a rail-wheel their complex interaction occur (fig. 1. *b*). It should also take into account that in the experiment there was no shift the contact area of the rail sample with the counter-sample. In the real contact of the rail-wheel, the contact area shifts along the rail due to movement of the wheel. Accordingly, the contact of the wheel with the rail in a certain area lying on the contact surface of the rail occurs for a short time. It does not coincide with the experiment where the contact zone is constant and in the process undergoes a constant influence of the friction force, which leads to a significant increase in the wear intensity.

The friction force in fig. 1. *a* will be determined as [8]:

$$F_f = P \cdot f , \quad (5)$$

where *f* is the friction coefficient, *P* is the normal force.



a *b*

Fig. 1. Friction model: *a* – in the experiment (*1* – rail sample, *2* - counter-sample), *b* – in the real contact wheel and rail

The friction force in fig. 2. *a* will be determined as [8]:

$$F'_f = P' \cdot f' , \quad (6)$$

where f' is the traction coefficient; P' is the normal force. The engine torque M_w creates the pair of forces F_1 and F_2 that act on the force arm *R* equals to the radius of the wheel. These forces tend to rotate the wheel around its axis. To obtain translational motion, an external force is required to apply to the driving wheels. This force is the horizontal reaction of the rail F'_f which caused by the action of the force F_2. The rail reaction force F'_f balanced the force F_2 and thereby released the force F_1 for the translational movement of the train.

Then we have to integrate the obtained dependence (2) from the experiment into the scheme of real contact of the wheel with the rail.

As known from the literature that load has a nonlinear effect on wear intensity [8]:

$$I \sim p^{1+\beta m} , \quad (7)$$

where β is coefficient, the $\beta = \frac{1}{2\nu + 1}$, m is the fatigue curve exponent, for steel which has tensile ultimate strength σ_{ul} = 800 MPa the $m = 8$ [9]. ν is the exponent of the material ratio curve (Abbot-Firestone curve). The material ratio curve characterizes the distribution of the material along the height of the rough layer. It built based on the roughness profile (fig. 2) [10]. Values of the material ratio curve ν determined in the paper [11] depending on the surface roughness of the rail.

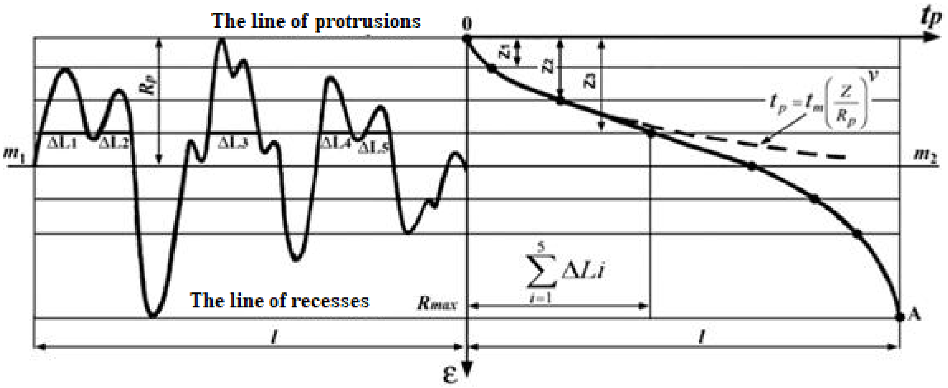


Fig. 2. The material ratio curve (Abbot-Firestone curve): ε is a profile height; t_p is a supporting length; R_p is the distance from the line of protrusions to the midline (the line m_1-m_2); t_m is the relative supporting length of the profile along the midline (the line m_1-m_2); R_{max} is the distance between the line of protrusions and the line of recesses within the base length of the surface profile l; Z_j is a row of horizontal levels; ΔL_i is a width of the protrusions at the level Z_j under consideration

This dependence (7) is in good agreement with the large number of experimental data for various materials including metals [12].

If the relationship between the friction coefficient and current load seems more complicated than in the previous case, then it is necessary to combine in one complex the frictional characteristics and load. Then dependences (7) has the next form [8]:

$$I \sim p^{1+\beta m-m} \cdot \tau_f^m , \tag{8}$$

where τ_f is the friction load referred to the unit of the nominal contact area.

The friction force for model of friction in fig 1. *a* is equal:

$$\tau_f = p_{\exp.} \cdot f , \tag{9}$$

where $p_{\exp.}$ is the contact pressure in the experiment.

The friction load for model of friction in fig 1.*b* is equal:

$$\tau'_f = p_{c.} \cdot f' , \tag{10}$$

where p_c is the contact pressure in the contact area rail-wheel.

The normal force *P* (fig. 1.*a*) in the experiment is equal *P* = 100 *N*.

The maximum contact pressure in the experiment:

$$p_{\exp.}^{\max} = 0.418\sqrt{\frac{P \cdot E_{eqv}}{b \cdot R}} = 0.418\sqrt{\frac{100 \cdot 215000}{10 \cdot 20}} = 137.05 \text{ MPa} , \tag{11}$$

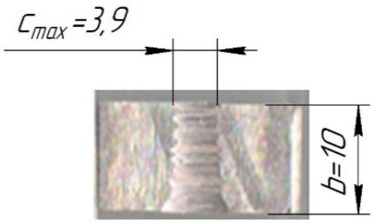


Fig. 3. Photo of a sample cut out of a rail with the dimensions of the wear zone

where *R* is the radius of the counter-sample (Fig. 1.*a*); E_{eqv} is the equivalent modulus of elasticity of the contact surfaces, E_{eqv} = 215000 MPa; *b* - the width of the sample (Fig. 3).

According to Fig. 3 the contact area of the sample from the tribological experiment is equal $S_{samp.} = b \cdot c_{\max.} = 3.9 \cdot 10 = 39 \text{ mm}^2$.

The minimum contact pressure in the experiment:

$$p_{\exp.}^{\min} = \frac{P}{S_{\text{samp.}}} = \frac{100}{39} = 2.56 \text{ MPa} . \tag{12}$$

Then the average contact pressure is equal: $p_{\exp.\,aver.} = \dfrac{p_{\exp}^{\min} + p_{\exp}^{\max}}{2} = \dfrac{137.05 + 2.56}{2} = 69.8 \text{ MPa}$.

For one kilometer of the path length of the counter-sample in the experiment, it performed the number of revolutions, which equals:

$$N = \frac{t_{\exp.}}{T \cdot L_{\exp.}} , \tag{13}$$

where $t_{\exp}$ is the time of the experiment, $t_{\exp} = 1$ $h = 7200$ s; T is a period one revolution, $T = \frac{1}{n} = \frac{1}{490} = 0.00204$ min $= 0.122$ s ; $L_{\exp.}$ is the total path length of the counter sample, $L_{\exp.} = 3.6$ km.

Then the number of revolutions of the counter – sample: $N = \frac{7200}{0.122 \cdot 3.6} = 16393.4 \ \frac{1}{\text{km}}$.

It is possible to calculate half of the contact area using the Hertz problem of contacting a cylinder with a plane [13]:

$$c_{\min} = 0.798\sqrt{2 \cdot P \cdot R(\theta_1 + \theta_2)} , \tag{14}$$

where R is the radius of the counter-sample, $R = 20$ mm; θ_1 and θ_2 is coefficients.

$$\theta_1 = \frac{1-\mu_1^2}{E_1} , \tag{15}$$

$$\theta_2 = \frac{1-\mu_2^2}{E_2} , \tag{16}$$

where μ_1 and μ_2 is Poisson's Ratios rail and wheel, E_1 and E_2 is Young's Modulus rail and wheel.
The perimeter of the counter sample is $L = 2 \cdot \pi \cdot R = 2 \cdot 3.14 \cdot 20 = 125.6$ mm.

We introduce the concept of the relative length of the contact zone to take into account the short-term contact, which would be during the rolling of the counter-sample along the sample as in the real process of contact of the wheel and rail. The relative length of the contact area during rolling

$$\Delta l = \frac{2c_{\min}}{L} . \tag{17}$$

The wear intensity is also proportional to the work of the friction forces. The contact area between the wheel and the rail is larger than if the counter-sample rolled over the sample in the experiment. We consider this as a relative area:

$$\Delta S = \frac{S_{c.\,r-w.}}{S_{c.\exp.}} , \tag{18}$$

where $S_{c.\,r-w.}$ is the contact area between the wheel and the rail; $S_{c.\exp.}$ is the contact area in the experiment if the counter-sample rolled over the sample, $S_{c.\exp.} = 2c_{\min} \cdot b = 2 \cdot 0.1473 \cdot 10 = 2.95 \text{ mm}^2$.

The final formula for calculating the rail wear intensity in real contact has form:

$$I_{\text{rail}} = \frac{I \cdot \Delta S \cdot \Delta l \cdot p_{c.}^{1+\beta m}}{N \cdot p_{\exp.\,\text{aver.}}^{1+\beta m}} \cdot \left(\frac{f'}{f}\right)^m . \tag{19}$$

The rail-wheel contact simulation performed in ANSYS Workbench. Static Structural analysis system used for simulation the rail-wheel contact. Mechanical properties of the rail material introduced into the program. It shown in table 1. SolidWorks program used to create 3D models of rail, wheel and wheel axis. These models imported into Ansys program. The 3D rail model corresponds to the sizes and shape of the rail type *R*65 [14]. The 3D model of the wheel corresponds to the sizes and shape (fig. 4), which lists in the standard [15]. Type of the rail-wheel contact selected as friction with the friction coefficient of 0.11. Type of the wheel-axis contact selected as bonded. Model parts divided into tetrahedral finite elements (fig. 5) with a decrease in the size of the elements in the contact zone of the wheel and rail. The size of the elements in the contact zone reduced to 6 mm (side of the element). The force applied to the wheel axis perpendicular to the rail surface and amounted to 85750 *N* (we accepted that the weight of a loaded train car is 70 tons). The rail fixed in the model. The number of calculation steps was equal 1. Step end time was equal 0.001 *s*.

Table 1

Mechanical properties of the rail material

Young's Modulus (MPa)	Poisson's Ratio μ	Tensile Ultimate Strength (MPa)	Tensile Yield Strength (MPa)
215000	0,29	980	780

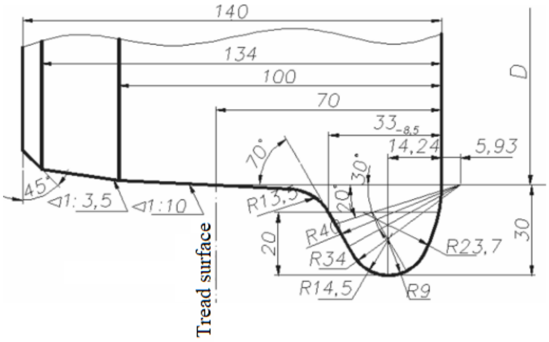


Fig. 4. Dimensions and surface shape of the wheel tread surface

It is necessary to know the amount of contact pressure acting on the rail surface from the wheel to determine the rail wear intensity. You can see in fig. 6 and fig. 7 contact pressure calculation result. Normal pressure on tread surfaces of the rail and wheel depends on the load of the wheel on the rail, radiuses of tread surfaces, properties of the interacting materials [16]. The radius of the tread surface depends on the contact area of the wheel and the rail. High contact stressses result from an extremely small contact area.

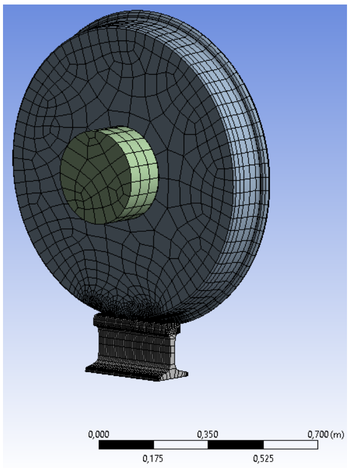


Fig. 5. Model parts divided into tetrahedral finite elements

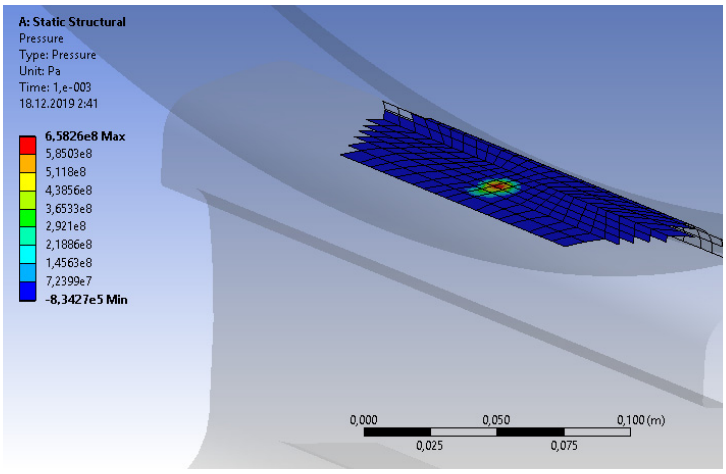


Fig. 6. The contact pressure on the contact surface of the rail

The area of contact of the wheel with the rail is in the form of an ellipsoid (fig. 8) with the dimensions of the axles of the contact ellipse: j = 12.6 mm (the big axis); k = 13.18 mm (the small axis). Then, in a simplified way, you can calculate the contact area of the wheel with the rail as the area of the ellipse – $S_{c.r-w.} = \pi \cdot \frac{j}{2} \cdot \frac{k}{2}$.

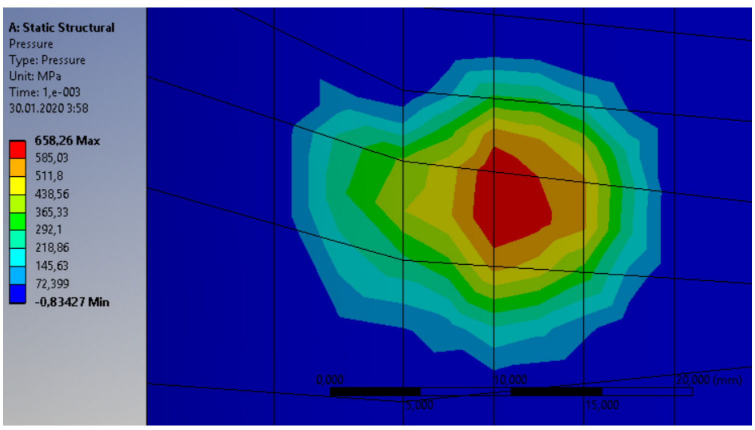


Fig. 7. The distribution of the magnitude of the contact pressure on the contact surface of the rail

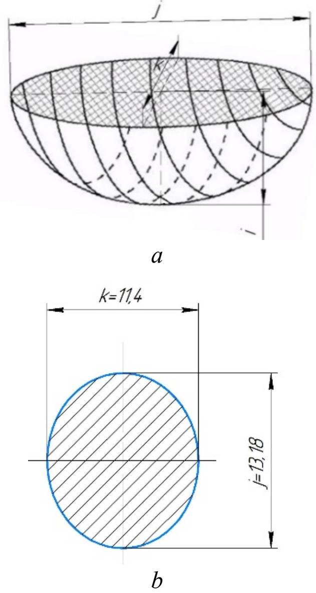


Fig. 8. The area of contact of the wheel with the rail: *a* – ellipsoid contact area; *b* – contact ellipse of the contact ellipsoid

The wear intensity value calculated in Ansys program using a subroutine which algorithm shown in fig. 9. *b*. The calculation is made in one step load.

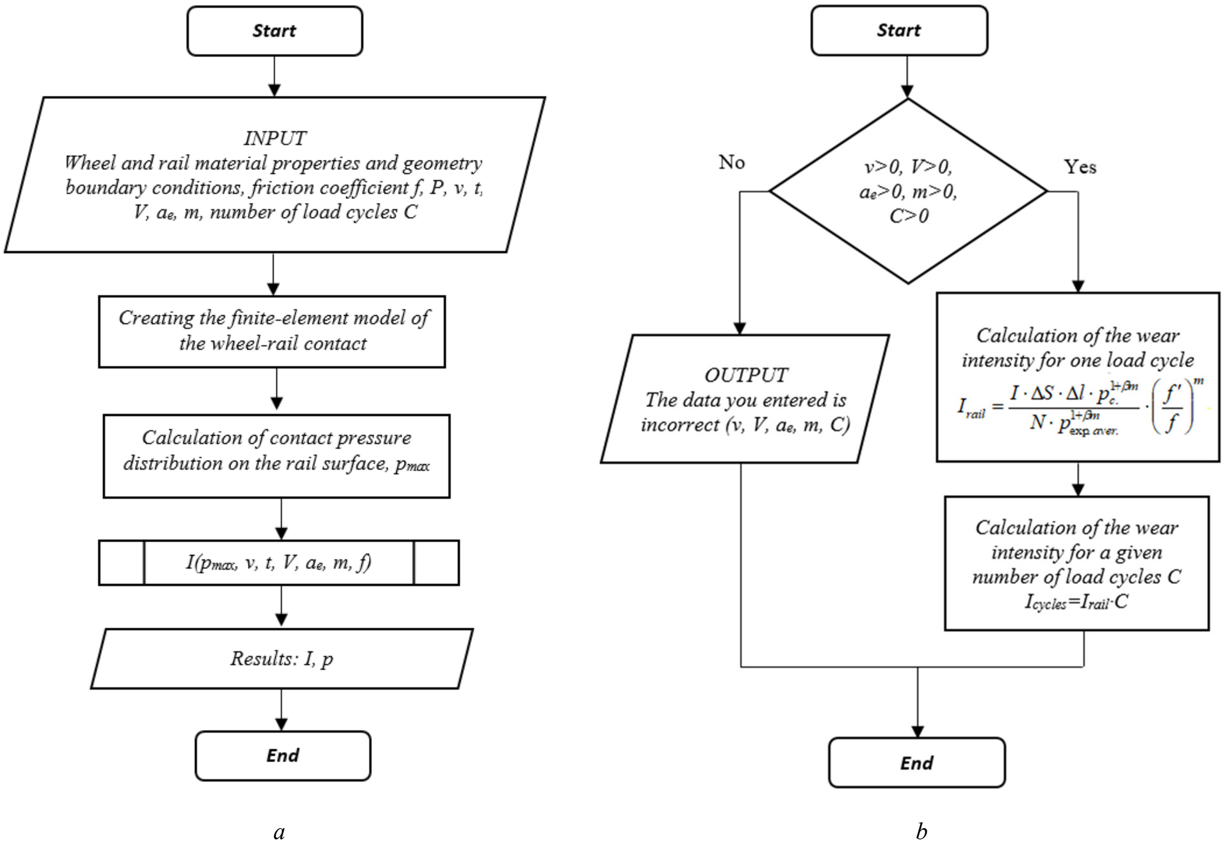


Fig. 9. The algorithm for calculating the rail wear intensity in the ANSYS program: *a* – the algorithm of the main program, *b* – the algorithm of the subroutine for calculation the rail wear intensity

Known paper [17], which gives experimental results on the values of the rail wear intensity depending on rails types and the amount of missed tonnage.

From this paper it is known that for R65 rails the average wear intensity from the amount of missed tonnage is equal 0.12 mm / ml. tons. Calculation according to the above method using parameters that shown in table 2.

Table 2

Data to calculate the rail wear intensity

I, mg/km [7]	ν [11]	P', N	m	C (number of load cycle)	f	f'
3	1.63	85750	8	116618.075	0.15	0.11

In the calculations it was accepted that I = 3 mg / km (the average value from the tribological experiment [7]). The calculated value of the intensity of the wear of the rail is 15 mg/ ml. tons for the number of load cycles C, which corresponds to passed 1 million tons cargo. Then the linear wear intensity with taking into account the ellipsoidal contact area (fig.8.*a*) is equal 0,176 mm / ml. tons. This value is close to the experimental data presented in the paper (the average wear intensity for the R65 rail is equal 0.12 mm / ml. tons) [17].

Conclusion

1) The empirical dependence of the influence of the parameters (temperature t, grinding depth of cut a_e, grinding wheel speed V).of the grinding rails process on their wear resistance obtained by analysing the results of the tribological experiment given in [7]. The contact conditions of a rail sample with a counter-sample during a tribological experiment

and in a real contact of a system rail–wheel are different. Therefore, the indicated dependence (2) is valid for predicting the wear intensity of rail samples when performing an experiment on a friction machine.

2) The obtained empirical dependence modified to be able to determine the wear intensity of the rail under conditions of real contact of the wheel–rail system. In the process of modification, the following differences of tribological experiments on the friction machine M-22M from the actual conditions of the contact of the wheel–rail system taken into account: different friction patterns, different contact pressure and different area of the contact spot of the wheel with the rail.

3) A numerical model has created in the Ansys program, which allows us to determine the contact pressure from the wheel-rail contact area and based on these data calculate the predicted value of the rail wear intensity depending on the number of load cycles.

4) The simulation results compared with the experimental wear intensity of the R65 type rails, which given in paper [17], but the grinding modes are not indicated there. The comparison shows the proximity of the obtained data from modelling using the dependence (19) for calculating the rail wear intensity and the results in the paper [17]. However, the model requires further checks and improvements to improve the accuracy of calculating the predicted wear intensity depending on the parameters of the grinding process.

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Створення трибологічної моделі контактного зношування залізничних рейок залежно від параметрів процесу шліфування

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Проблематика. *Сучасні умови експлуатації залізничного транспорту характеризуються збільшенням потужностей локомотивів, швидкостей руху поїздів, вантажопідйомності вагонів, що призводить до збільшення силових впливів на залізничну колію. Екстремальні умови експлуатації призводять до збільшення зношування і пошкодження рейок, від надійності яких залежить не тільки безпеку руху, а й економічні показники діяльності залізниці. Шліфуванням рейок виконують видалення дефектних шарів матеріалу з їх поверхні. Таким чином забезпечуються необхідні розміри і точність форми, а також якість поверхні рейок в процесі їх експлуатації.*

Мета дослідження. *Розробка трибологічної моделі контактного зношування рейок під час їх експлуатації залежно від параметрів процесу шліфування (температура t, припуск на обробку a_e, лінійна швидкість шліфувального круга V).*

Методика реалізації. *Дослідження зношування та контактного пошкодження поверхонь зразків, вирізаних із шліфованих рейок, проводилися на машині тертя М-22М. Дослідження здійснювались шляхом сухого тертя зразка (вирізаний з рейки) із контрзразком з матеріалу, що використовується при виготовленні залізничних коліс, протягом 1 години при цьому шлях тертя складав – 3,60 км. Зразки зважувались на вагах ВЛР-200 до та після виконання дослідження на машині тертя. В результаті для кожного зразка було визначено величину масового зношування. В програмі ANSYS створена чисельна модель для моделювання методом скінчених елементів контакту колеса з рейкою для встановлення розподілу контактних тисків та величини інтенсивності зношування рейки.*

Результати дослідження. *На основі результатів трибологічних досліджень була отримана емпірична залежність інтенсивності зношування зразка рейки від параметрів процесу шліфування. Оскільки умови контакту зразка рейки з контрзразком під час трибологічних досліджень та при реальному контакті колеса з рейкою різні, було виконано приведення отриманої емпіричної залежності до реальних умов контакту колеса з рейкою. Моделювання контакту колеса з рейкою виконувалось в програмі ANSYS. Залежності, що наведені в роботі, використовувались в програмі для обчислення інтенсивності зношування рейки відповідно до розподілу контактного тиску в контактній зоні колеса і рейки.*

Результати роботи можуть знайти практичне застосування на залізничному транспорті для прогнозування впливу параметрів процесу шліфування на інтенсивність зношування рейки.

Висновки. *На основі експериментальних даних, отриманих з трибологічних експериментів на машині тертя М-22М із шліфованими зразками рейок, була отримана залежність для наближеного вичначення інтенсивності зношування рейки в залежності від параметрів процесу шліфування (температура t, припуск на обробку a_e, лінійна швидкість шліфувального круга V). Розроблена математична модель для обрахунку контактного тиску та величини інтенсивності зношування рейки в залежності від кількості циклів навантаження в програмі ANSYS.*

Ключові слова: *шліфування рейок; інтенсивність зношування; поверхнева твердість; трибологічні властивості.*

Создание трибологической модели контактного изнашивания железнодорожных рельсов в зависимости от параметров процесса шлифования

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Проблематика. *Современные условия эксплуатации железнодорожного транспорта характеризуются увеличением мощностей локомотивов, скоростей движения поездов, грузоподъемности вагонов, что приводит к увеличению силовых воздействий на железнодорожный путь. Экстремальные условия эксплуатации приводят к увеличению износа и повреждения рельсов, от надежности которых зависит не только безопасность движения, но и экономические показатели деятельности железной дороги. Шлифовкой рельсов выполняют удаление дефектных слоев материала с их поверхности. Таким образом обеспечиваются необходимые размеры и точность формы, а также качество поверхности рельсов в процессе их эксплуатации.*

Цель исследования. *Разработка трибологической модели контактного износа рельсов в процессе их эксплуатации в зависимости от параметров процесса шлифования (температура t, припуск на обработку a_e, линейная скорость шлифовального круга V).*

Методика реализации. *Исследование износа и контактного повреждения поверхностей образцов, вырезанных из шлифованных рельсов, проводились на машине трения М-22М. Исследования осуществлялись путем сухого трения образца (вырезанный из рельса) с контробразцом из материала, используемого при изготовлении железнодорожных колес, в течение 1 часа при этом путь трения составлял – 3,60 км. Образцы взвешивались на весах ВЛР-200 до и после выполнения исследования на машине трения. В результате для каждого образца было определено величину массового износа. В программе ANSYS создана численная модель для моделирования методом конечных элементов контакта колеса с рельсом для установления распределения контактных давлений и величины интенсивности износа рельса.*

Результаты исследования. *На основе результатов трибологических исследований была получена эмпирическая зависимость интенсивности износа образца рельса от параметров процесса шлифования. Поскольку условия контакта образца рельса с контробразцом в процессе трибологических исследований и при реальном контакте колеса с рельсом разные, было выполнено приведение полученной эмпирической зависимости к реальным условиям контакта колеса с*

рельсом. Моделирование контакта колеса с рельсом выполнялось в программе ANSYS. Зависимости, приведенные в работе, использовались в программе для вычисления интенсивности износа рельса в соответствии с распределением контактного давления в контактной зоне колеса и рельса.
Результаты работы могут найти практическое применение на железнодорожном транспорте для прогнозирования влияния параметров процесса шлифования на интенсивность износа рельса.
***Выводы.** На основе экспериментальных данных, полученных с трибологических экспериментов на машине трения М-22М с шлифованными образцами рельсов, была получена зависимость для приближенного определения интенсивности износа рельса в зависимости от параметров процесса шлифования (температура t, припуск на обработку a_e, линейная скорость шлифовального круга V) . Разработана математическая модель для расчета контактного давления и величины интенсивности износа рельса в зависимости от количества циклов нагрузки в программе ANSYS.*
***Ключевые слова:** шлифование рельсов; интенсивность изнашивания; поверхностная твердость; трибологические свойства.*

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